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ORIGINAL RESEARCH

GLENOHUMERAL ROTATIONAL RANGE OF MOTION DIFFERENCES BETWEEN FAST BOWLERS AND SPIN BOWLERS IN ELITE CRICKETERS

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ABSTRACT

Background: The shoulder, particularly the glenohumeral joint with its predominant reliance upon soft tissues for stability is prone to injury among the cricketers who bowl regularly. These shoulder injuries are more common in spin bowlers than fast bowlers. A decreased internal rotational difference and increased external rotational difference exist when comparing the dominant shoulder with non-dominant shoulder between overarm cricketers and non-throwing wicket keepers.

Purpose: To compare the glenohumeral internal and external rotation range of motion differences between fast bowlers and spin bowlers.

Methods: A cross-sectional design was utilized for this study. Thirty-five fast bowlers and 31 spin bowlers from an elite group were recruited based on the selection criteria. Glenohumeral passive internal and external rotational differences between dominant and non-dominant shoulders were measured using a standardized mechanical inclinometer.

Results: Independent t-tests revealed a statistically significant difference for external rotational difference ($p = 0.005$) between fast and spin bowlers and no such difference for internal rotational difference ($p = 0.549$) between them at 0.05 level.

Conclusion: External rotational difference is significantly different between fast bowlers and spin bowlers but not internal rotational difference.

Level of Evidence: Level 4

Key words: External rotational difference, glenohumeral internal rotational deficit, glenohumeral joint, internal rotational difference.

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INTRODUCTION

In the sport of cricket, bowlers can be categorized as fast bowlers and spin bowlers.[1] All bowlers propel a 5.5 oz ball towards a batsman or his wickets, but a spin bowler imparts rotation to the cricket ball, which makes the ball deviate from its original direction of flight when it hits the ground. The spin bowler achieves this by rapid flexion of the fingers around one side of the ball, called "finger spin" or by rapid movements of the wrist as he or she releases the ball, called "wrist spin".[2]

Spin bowling contrasts with fast bowling when bowlers try to beat the batsmen by combinations of speed of delivery and deviations of the ball during flight, usually achieved by keeping the stitched seam of the cricket ball vertical and pointing towards the batsmen. Deviations may occur before the ball bounces, called "swing" or after the ball bounces, called "cut".[2]

During the overhead throwing motion the shoulder complex functions as a regulator of the forces generated by the legs and trunk.[3] It is this regulating function as well as the high velocities that accompany the throwing motion that place large forces and torques on the glenohumeral joint (GHJ). These forces as well as the frequent repetition of the overhead throwing action produce severe stresses on the muscles, bones, and joints of the upper extremity.[4] Overhead throwing athletes have been found to have greater internal/external rotation strength ratios in their dominant arm when compared to their non dominant arm.[5] This finding shows that the overhead throwing action places large amounts of stress on the shoulder which causes alterations of muscle strength patterns. During bowling in cricket, the internal shoulder rotators are involved in the acceleration phase of the arm through concentric contractions, while the external rotators are involved during the deceleration phase.[1]

Repetitive pitching at high velocities over time leads to chronic adaptations of soft[3,6] and osseous[7,8] tissues that comprise the GHJ. These anatomic adaptations likely lead to differences in range of motion (ROM) when shoulders are compared bilaterally[9-11] and when overhead-throwing athletes are compared with non-overhead-throwing athletes.[3,12] Although ROM changes may be adaptive, some changes in ROM are associated with pain,[13] decreased performance[3,13,14] and shoulder injuries.[3,15] Researchers have theorized that throwers experience an acute decrease in internal rotation (IR); however, these authors reported comparisons between throwing and nonthrowing shoulders,[13] between throwers and nonthrowers,[16] or among throwers of different ages.[13,17] In other previous studies[9,11,18] that have examined changes in overhead-throwing athlete's ROM, investigators stated that external rotation (ER) was increased and IR was decreased. When IR decreases beyond the gain in ER, the condition is called Glenohumeral Internal Rotation Deficit (GIRD).[3] Burkhart et al proposed that GIRD may be associated with injury and, therefore, suggested that clinicians assess rotational ROM of the GHJ in competitive throwers.[3]

A significantly greater reduction of glenohumeral IR and increase in glenohumeral ER have been reported in professional tennis players with shoulder pain, when compared to those without pain.[19] The mechanism for this adaptation has been attributed to their repetitive overhead activity which causes stretching of the anterior capsule and tightening of the posterior capsuloligamentous/muscular complex. These soft tissue adaptations may allow anteriosuperior migration of the humeral head, accounting for the development of subacromial impingement and shoulder pain.[6,20-22] In contrast to soft tissue adaptation, increased ER and decreased IR of dominant GHJ has also been attributed to bone remodeling of the humeral neck to a retroverted orientation, which may be a protective mechanism in order to reduce the risk of shoulder injury.[8,16,23,24]

Total shoulder ROM, elevation, and rotational motion, especially IR decrease with physical maturation during the developmental years.[11] The IR ROM deficit may be a clinical condition that results in other compensatory motion alterations often identified in overhead athletes. Therefore, overhead athletes should be monitored for motion changes throughout their competitive seasons.[25]

The England and Wales Cricket Board reported that 5.5% of all injuries among the First-Class County Cricketers, during the 2001 and 2002 seasons affected the shoulder and similar findings were reported in South Africa[9] (5.2%) and among the first-class Australian teams (7%).[26] Australian injury surveillance data encompassing the years 1995–2001, demonstrates that shoulder injury prevalence among batters was 0.3%, fast bowlers 0.9%, and spin bowlers as 1.1%.[26] Among the 113 bowlers from English Cricket Club centers fast bowlers had a greater incidence of low back pain and knee pain compared to the spin bowlers in January 1998.[2] Shoulder injuries were more common in fast bowlers with a front-on action than the bowlers with a side-on or semi front-on action and shoulder injuries were reported more among the wrist spinners than finger spinners. In wrist spin the bowlers appear to rotate the bowling shoulder internally, while the arm circumducts.[27] Gregory et al speculated that this action of IR during spin bowling may predispose one to impingement and injury.[2] It was documented that the the presence of possible dysfunction in the shoulder rotators, combined with a front-on bowling action and external rotation hypermobility are possible predisposing factors for chronic shoulder injuries in cricket fast bowlers.[27]

Decreased GHJ IR may be a risk factor for shoulder injuries when related to ER ROM and arm dominance in cricketers.[28] Giles and Musa reported that among the cricketers there is an increased internal rotational difference (IRD) value, indicating a greater loss of dominant to non-dominant GHJ internal rotation, and an association with a gradual onset of non-specific (GONS) shoulder pain.[29] Ellenbecker et al found no significant difference in active ER ROM between dominant and non-dominant arms for both males and females, but there was a significant reduction in active IR ROM on the dominant arms in both male and female elite junior tennis players.[30] Likewise increased ER and decreased IR ROM of the GHJ of the dominant to non-dominant sides has been well documented in a variety of unilateral overhead sports including volleyball, tennis, and baseball.[6,7,23,31,32]

It is common to measure GHJ rotational range of cricketers during musculoskeletal profiling, with the general recommendation that stretches be undertaken to reduce differences between dominant and non-dominant shoulders.[29] Glenohumeral internal and external rotational differences between dominant and non-dominant arms have already been examined in overarm cricketers and non-throwing wicket keepers and when comparing their rotational range of motion differences no significant differences were found in IRD or external rotation difference (ERD) between overarm cricketers and wicket keepers.[29] The authors are not aware of any investigations comparing the glenohumeral IRD and ERD between spin bowlers and fast bowlers. It could be anticipated that spin bowlers and fast bowlers who regularly bowl overarm would have differences in glenohumeral IRD and ERD as their bowling action differs. Therefore, the purpose of this study was to examine the Glenohumeral IRD and ERD between dominant and non-dominant arms of elite cricketers, as well as to compare these measures between fast bowlers and spin bowlers.

METHODS

Sixty-six male elite cricketers; 35 fast bowlers with a mean (SD) age of 17.97 (1.94) years and 31 spin bowlers with a mean (SD) age of 18.48 (3.68) years were recruited from five cricket academies. The participants with a history of shoulder or upper arm pain during a 48-hour period prior to shoulder measurement, any previous upper limb fractures and surgeries, previous shoulder injuries, those suffering from any other neurological disorders, and those regularly participating in other overhead sports other than cricket were excluded from the study.

This study was approved by the ethical and scientific review committee of the institution. The participants were clearly instructed about the study before obtaining written consent. Measurements were taken during on-season training sessions between June and July of 2010. Cricketers' demographic details were collected using a questionnaire. The questionnaire was designed to collect data related to the upper limb demands of cricket, including arm dominance for bowling, and bowling type. Information was also collected related to bowling practice sessions per year, month, week and day; number of overs bowled during a practice session and match; and additional overhead sporting activities that subjects participated in. Details of subjects' previous upper limb injuries were also collected. Isolated, passive ROM (PROM) of IR and ER were measured for dominant and non-dominant GHJs' of all participants using a mechanical inclinometer with established excellent intra- and inter-rater reliability.[33]

PROCEDURE

Before measurements were performed, participants were allowed to perform a 5-minute warm-up program of active shoulder circumduction in clockwise and counterclockwise directions in order to reduce the risk of shoulder injury. During measurements, the participants were asked to lie supine with legs straight, neutral cervical rotation and 90° shoulder abduction, approximating the late cocking phase of the throwing position.[31,34] The examiner passively rotated the GHJ to end range on two consecutive occasions prior to measuring to familiarize the participant with the movement. Movement was isolated to the GHJ during IR[14,31,35] by maintaining pressure on the coracoid process, clavicle and posterior spine of the scapula, while palpating the head of the humerus. End range was the point at which anterior humeral head translation was initiated. The same examiner performed all measurements. The inclinometer was placed on the volar aspect of the distal forearm near wrist for measuring ER and was placed on the dorsal aspect of the distal forearm near wrist to measure IR. The examiner was blinded to the inclinometer reading and cricketer's arm dominance. After measuring IR and ER of both the upper limbs, difference in IR and ER between dominant and non-dominant limbs were calculated and recorded as IRD and ERD.

RESULTS

Data analysis was performed using the statistical software SPSS 16 (Chicago, IL). Descriptive analysis was done for all the basic characteristics of the participants including age, height, weight, hand dominance, and other sport specific characteristics like maximum level of game participation, experience, warm-up session for shoulder, cool-down session for shoulder, and shoulder specific exercises (Table 1). The descriptive statistics for the variables related to cricket practice sessions per year, month, week, and day are presented in Table 2. Table 3 displays the descriptive statistics for the variables, number of overs bowled during a practice session and match. Mean and standard deviation of ER and IR PROM of left and right GHJs of right handed fast and spin bowlers and left handed fast and spin bowlers were calculated separately (Table 4). Mean (SD) of IRD (in degrees) for fast bowlers and spin bowlers were 11.58 (+/-10.70) and 12.90 (+/-6.21) respectively and of ERD for fast bowlers and spin bowlers are 15.23 (+/-9.36) and 23.46 (+/-13.38) respectively.

Pearson correlation coefficient was used to examine correlations between IRD and ERD and age (r = -0.120 and r = -0.013), years of experience (r = 0.093 and r = 0.059), number of overs bowled during a practice session (r = -0.102 and r = -0.097) and match (r = 0.358 and r = -0.105) and none of the variables was significantly correlated with IRD and ERD at 0.05 level in fast bowlers (Table 5). Similarly in spin bowlers also no significant correlation was obtained for IRD and ERD with age (r = 0.083 and r = 0.142), years of experience (r = -0.171 and r = 0.123), number of overs bowled during a practice session (r = -0.158 and r = 0.231) and match (r = 0.040 and r = -0.159) at 0.05 level (Table 5).

The comparison of mean IR PROM and ER PROM of dominant and non-dominant sides of fast and spin bowlers revealed a statistically significant difference only for right handed fast bowlers in both ER PROM (p = 0.014) and IR PROM (p = 0.013) and right handed spin bowlers in both ER PROM ($p < 0.0001$) and IR PROM (p = 0.048), whereas left handed fast and spin bowlers did not show a statistically significant difference in both ER PROM and IR PROM at 0.05 level as tested by an independent t-test. The IRD and ERD values were compared between the fast bowlers and spin bowlers by using an independent t-test. A statistically significant difference was found in ERD (p = 0.005) between the fast bowlers and spin bowlers, whereas no significant difference was found for IRD (p = 0.549) between groups at 0.05 level (Table 6).

DISCUSSION

The results of this study indicate that spin bowlers and fast bowlers who bowl regularly have decreased GHJ IR and increased ER ROM in dominant shoulders compared to non-dominant shoulders. Similar results have been reported in other overhead athletes.[6,7,16,19,22,31,32] The significant differences observed only for right handed fast bowlers (n = 31) and spin bowlers (n = 28) in both ER PROM and IR PROM between their dominant and non-dominant GHJs may be because only a few left handed fast bowlers (n = 4) and spin bowlers (n = 3) participated in this study.

Table 1. *Description of subjects.*

Characteristic	Fast Bowlers (N=35) Mean (SD)	Spin Bowlers (N=31) Mean (SD)
Age (years)	17.97 (1.94)	18.48 (3.68)
Height (feet inches)	5.7 (0.40)	5.55 (0.33)
Weight (kilograms)	62.65 (11.76)	63.03 (13.26)
Hand Dominance – n(%)		
Right	31 (88.6)	28 (90.3)
Left	4 (11.4)	3 (9.7)
Highest level of participation - n(%)		
National	3 (8.6)	3 (9.7)
State	32 (91.4)	28 (90.3)
Experience (years) - n(%)		
1 – 5	26 (74.3)	22 (71)
6 - 10	9 (25.7)	9 (29)
Warm up Session for Shoulder - n(%)		
No	1 (2.9)	0 (0)
Yes	34 (97.1)	31 (100)
Cool down Session for Shoulder - n(%)		
No	8 (22.9)	9 (29)
Yes	27 (77.1)	22 (71)
Shoulder Exercises - n(%)		
No	14 (40)	14 (45.2)
Yes	21 (60)	17 (54.8)

These GHJ rotational changes may be attributed to repeated overhead or throwing activity causing capsuloligamentous and muscular micro-trauma, with particular reference to stretching of the anterior capsule and contracture of the posterior–inferior capsule.[13,21,22] This mechanism of soft tissue adaptation is supported by Hsu et al, who stretched the posterior glenohumeral joint capsule of cadaveric shoulders and demonstrate increased internal rotation,[36] and by Burkhart and colleagues, who reported that, in their experience, internal rotation could be increased with posterior capsule stretches.[3] Similarly, McClure et al found a clinically significant improvement in IR ROM following the cross-body stretch compared to that of the sleeper stretch among the asymptomatic recreational athletes.[37] Manske

Table 2. *Practice sessions per year, month, week and day.*

Number of practice sessions	Fast Bowlers (N=35) n (%)	Spin Bowlers (N=31) n (%)	*p* value[a]
Per year			
1-4 months	2(5.7)	1(3.2)	
5-8 months	7(20)	13(41.9)	
9-12 months	26(74.3)	17(54.8)	0.150
Per month			
1 week	0(0)	2(6.5)	
2 weeks	3(8.6)	2(6.5)	
3 weeks	12(34.3)	4(12.9)	
4 weeks	20(57.1)	23(74.2)	0.103
Per week			
2 days	1(2.9)	1(3.2)	
3 days	5(14.3)	4(12.9)	
4 days	1(2.9)	3(9.7)	
5 days	13(37.1)	11(35.5)	
6 days	8(22.9)	9(29.0)	
7 days	7(20.0)	3(9.7)	0.745
Per day			
1-2 hours	16(45.7)	18(58.1)	
2.5-4 hours	13(37.1)	9(29.0)	
5-7 hours	6(17.1)	4(12.9)	0.605

[a] *p* values were calculated by using chi-square test

et al also reported that the posterior shoulder mobility can be increased by providing cross-body stretch alone or cross-body stretch plus joint mobilization techniques in asymptomatic athletes.[38]

An alternative explanation for this altered GHJ rotation in fast bowlers and spin bowlers is osseous adaptation of humeral retroversion in response to repetitive overhead activity, with decreased IR and equivalently increased ER.[8,16,23,24] The findings of this study are in agreement with Giles and Musa who examined GHJ IR and ER differences between dominant and non-dominant shoulders in cricketers who bowl and throw overarm regularly.[29] The present study showed a mean IRD of 11.58° and 12.90° for fast and spin bowlers respectively and mean ERD of 15.23° and 23.46° for fast bowlers and spin bowlers respectively which are more than the mean IRD (-7.9°) and ERD (8.6°) obtained by Giles and Musa.[29] These higher values may be attributed to the inclusion of bowlers alone rather than all the cricketers (throwers, fielders, wicket keepers). In the same study Giles and Musa reported that there was no significant difference between the overarm cricketers (who regularly bowl and throw) and wicket keepers in their GHJ IR and ER differences, which is partially consistent with the findings of no significant IRD between fast bowlers and spin bowlers. However, this was inconsistent with the current study finding of significant ERD between fast bowlers and spin bowlers.[29]

Injury surveillance data collected in Australia during the year 1995-2001 indicates that shoulder injury

Table 3. *Number of overs bowled during a practice session and match.*

Number of overs bowled	Fast Bowlers (N=35) n (%)	Spin Bowlers (N=31) n (%)	*p* value[a]
During a practice session			
1-5	4(11.4)	1(3.2)	
6-10	17(48.6)	19(61.3)	
11-15	12(34.3)	7(22.6)	
16-20	2(5.7)	4(12.9)	0.300
During a match			
1-5	3(8.6)	2(6.5)	
6-10	27(77.1)	24(77.4)	
11-15	4(11.4)	3(9.7)	
16-20	1(2.9)	2(3.4)	0.619

[a] *p* values were calculated by using chi-square test

Table 4. *Mean PROM of ER and IR of GHJ for right handed and left handed participants.*

Hand Dominance	Fast Bowlers (N=35) Mean (SD)	Spin Bowlers (N=31) Mean (SD)
Right handed participants		
Rt.ER§	144.49 (16.58)	150.15 (14.96)
Rt.IR#	104.79 (14.97)	94.68 (19.20)
Lt.ER†	129.56 (15.53)	127.27 (9.49)
Lt.IR‡	112.79 (11.64)	104.29 (17.92)
Left handed participants		
Rt.ER§	136.99 (11.07)	146.33 (17.24)
Rt.IR#	116.16 (10.16)	108.11 (10.86)
Lt.ER†	154.83 (16.40)	153.55 (20.03)
Lt.IR‡	114.74 (6.10)	108.22 (17.81)

PROM: Passive range of motion; **GHJ:** Glenohumeral joint; § External rotation of right shoulder (in degrees); # Internal rotation of right shoulder (in degrees); †External rotation of left shoulder (in degrees); ‡ Internal rotation of left shoulder (in degrees)

Table 5. *Correlation between IRD and ERD with other characteristics of participants.*

Variable	IRD†		ERD‡	
	Fast Bowlers	Spin bowlers	Fast Bowlers	Spin Bowlers
	r (*p* value)	*r* (*p* value)	*r* (*p* value)	*r* (*p* value)
Age	-0.120 (0.494)	0.083 (0.659)	-0.013 (0.943)	0.142 (0.446)
Years of experience	0.093 (0.594)	-0.171 (0.357)	0.059 (0.735)	0.123 (0.510)
Number of overs bowled during a practice session	-0.102 (0.561)	-0.158 (0.396)	-0.097 (0.580)	0.231 (0.210)
Number of overs bowled during a match	0.358 (0.035)	0.040 (0.830)	-0.105 (0.548)	-0.159 (0.392)

† Internal rotational difference; ‡ External rotational difference

Table 6. *Rotational difference of GHJ between fast bowlers and spin bowlers.*

Rotational difference (measured in degrees)	Fast Bowlers (N=35) Mean (SD)	Spin Bowlers (N=31) Mean (SD)	Mean difference (95% CI)	t Statistic	*p* value
IRD†	11.58 (10.70)	12.90 (6.21)	-1.32 (-5.71, 3.07)	-0.602	0.549
ERD‡	15.23 (9.36)	23.46 (13.38)	-8.23 (-13.86, -2.60)	-2.919	0.005*

GHJ: Glenohumeral joint; † Internal rotational difference; ‡ External rotational difference; * *p* value significant at 0.05 level

prevalence among pace bowlers was 0.9% and spin bowlers was 1.1%.[26] Similarly, Gregory et al reported that 10% of fast bowlers and 16.7% of spin bowlers developed shoulder injuries.[2] This increased prevalence of shoulder injuries among the spin bowlers may be associated with increased ERD values as was demonstrated in the findings of the current study.

Rotational motion differences between dominant and non-dominant shoulders of baseball players grew larger as the age increases.[11] Even though the present study found a difference in IRD between fast bowlers and spin bowlers it was not statistically significant. The explanation for this failure to detect significant IRD between the groups may be because of the lower mean age (18.21 years) of the bowlers. The prior study that demonstrated a significant difference in IRD had a mean subject age of 30 years.[39]

Kibler and colleagues found a significant correlation between increasing IRD with both increasing age and years of tennis exposure, supporting an adaptive change in response to repetitive overhead activity among 39 high level tennis players.[32] In the present study, variables like age and years of experience are correlated with ERD and IRD among the fast bowlers and spin bowlers, which showed a negative correlation of age with IRD in fast bowlers and a positive correlation of age with ERD in fast bowlers and with both IRD and ERD in spin bowlers, it also showed a negative correlation for years of experience with IRD in spin bowlers, positive correlation for years of experience with ERD in spin bowlers and with both ERD and IRD in fast bowlers. Though those variables (age and years of experience) are linearly related with IRD and ERD in fast bowlers and spin bowlers they are not significant. The possible reasons for this finding may be due to a lower mean subject age (18.21 years) and also because the cricket players are involved in several tasks like fielding, wicket keeping and batting along with bowling, which may contribute less stress to their GHJs when compared to tennis players. With these findings it is apparent that bowling action of respective types plays a major role in the changes that are present in GHJ rotational PROM in cricket bowlers rather than other variables.

LIMITATION, STRENGTH AND RECOMMENDATION

The present study did not differentiate the fast bowlers into sub-types including front-on, side-on and mixed action bowlers, or the spin bowlers into wrist spinners or finger spinners. Recording the different sub-types of bowling technique may have given further information regarding the GHJ rotational range orientation among different types of fast bowlers and spin bowlers.

To the knowledge of the authors, this is the first study to report the GHJ IRD and ERD between fast bowlers and spin bowlers. It is also the first study to report significantly higher GHJ ERD values for spin bowlers than fast bowlers. As there is lack of research regarding spin bowlers GHJ rotational range of motion differences, the current study has laid a path for future research in shoulder PROM of elite cricketers. Additionally, higher values of ERD in spin bowlers found in present study warrants further research with detailed kinematic analysis of fast bowling and spin bowling in order to determine the biomechanics of respective types of bowling and factors that may cause higher ERD values in spin bowlers.

CONCLUSION

A significant ERD difference exists between elite fast bowlers and spin bowlers, but there is no such difference in IRD between them and this difference may be due to their bowling actions rather than other variables. Both fast and spin bowlers have decreased GHJ IR and increased ER PROM in dominant shoulders compared to non-dominant shoulders.

REFERENCES

1. Codine P, Bernard PL, Pocholle M, et al. Influence of sports discipline on shoulder rotator cuff balance. *Med Sci Sports Exerc.* 1997;29:1400-1405.
2. Gregory PL, Batt ME, Wallace WA. Comparing injuries of spin bowling with fast bowling in young cricketers. *Clin J Sport Med*. 2002;12:107-112.
3. Burkhart SS, Morgan CD, Kibler WB. The disabaled throwing shoulder: spectrum of pathology part I: Pathoanatomy and Biomechanics. *Arthroscopy.* 2003;19:404-420.
4. Bartlett RM, Stockill NP, Elliot BC, et al. The Biomechanics of fast bowling in men's cricket: a review. *J Sports Sci.*1996;14:403-424.
5. Meister K. Injuries to the shoulder in throwing athlete. *Am J Sports Med.* 1996;28:587-601.
6. Bigliani LU, Codd TP, Connor PM, et al. Shoulder motion and laxity in the professional baseball player. *Am J Sports Med*. 1997;25(5):609–613.
7. Baltaci G, Johnson R, Kohl H. III Shoulder range of motion characteristics in collegiate baseball players. *J Sports Med Phys Fitness*. 2001;41(2):236–242.
8. Reagan KM, Meister K, Horodyski MB, et al. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med*. 2002;30(3):354–360.
9. Borsa PA, Dover GC, Wilk KE, et al. Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc*. 2006;38(1):21–26.
10. Downar JM, Sauers EL.Clinical measures of shoulder mobility in the professional baseball player. *J Athl Train*. 2005;40(1):23–29.
11. Meister K, Day T, Horodyski M, et al. Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. *Am J Sports Med*. 2005;33(5):693–698.
12. Burkhart SS, Morgan CD, Kibler WB. Shoulder injuries in overhead athletes: the "dead arm" revisited. *Clin Sports Med*. 2000;19(1):125–158.

13. Ruotolo C, Price E, Panchal A. Loss of total arc of motion in collegiate baseball players. *J Shoulder Elbow Surg*. 2006;15(1): 67–71.

14. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, part III. The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003;19(6):641–661.

15. Myers JB, Laudner KG, Pasquale MR, et al. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34(3):385–391.

16. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med*. 2002;30(1):20–26.

17. Levine WN, Brandon ML, Stein BS, et al. Shoulder adaptive changes in youth baseball players. *J Shoulder Elbow Surg*. 2006;15(5):562–566.

18. Norkin CC, White DJ. Measurement of Joint Motion: A Guide to Goniometry. Philadelphia, PA: FA Davis Co; 1985:35–37.

19. Vad VB, Gebeh A, Dines D, et al. Hip and shoulder internal rotation range of motion deficits in professional tennis players. *J SciMed Sport.* 2003;6: 71-75.

20. Halbrecht JL, Tirman P, Atkin D. Internal impingement of the shoulder: comparison of findings between the throwing and non-throwing shoulders of college baseball players. *Arthroscopy.* 1999;15:253–258.

21. Tyler TF, Nicholas SJ, Roy T, et al. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med*. 2000;28:668–673.

22. Wilk K, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. *Am J Sports Med*. 2002;30:136–151.

23. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med*. 2002;30:347–353.

24. Pieper HG. Humeral torsion in the throwing arm of handball players. *Am J Sports Med*. 1998;26:247–253.

25. Thomas SJ, Swanik KA, Swanik C, et al. Glenohumeral rotation and scapular position adaptations after a single high school female sports season. *J Athl Train.* 2009;44 (3):230–237.

26. Orchard J, James T, Alcott E, et al. Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. *Br J Sports Med.* 2002;36(1):39-44.

27. Aginsky KD, Lategan L, Stretch RA. Shoulder injuries in provincial male fast bowlers-predisposing factors. *S Afr J Sports Medicine.* 2004;16(1)25-28.

28. Bell-Jenje TC, Gray J. Incidence, nature and risk factors in shoulder injuries of national academy cricket players over 5 years – a retrospective study.*S Afr JSports Medicine.* 2005;17(4):22-28.

29. Giles K, Musa I. A survey of glenohumeral joint rotational range and non-specificshoulder pain in elite cricketers. *Phys Ther Sport.* 2008;9:109–116.

30. Ellenbecker TS, Roetert EP, Piorkowski PA, et al. Glenohumeral joint internal and external rotation range of motion in elite junior tennis players. *J Orthop Sports Phys Ther.* 1996;24(6):336-341.

31. Ellenbecker TS, Roetert EP, Bailie DS, et al. Glenohumeral joint total range of rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc.* 2002;(34):2052–2056.

32. Kibler WB, Chandler JT, Livingstone BP, et al. Shoulder range of motion in elite tennis players: Effect of age and years of tournament play. *Am J Sports Med.* 1998;26:247.

33. Tripp BL, Dwelly PM, Odai ML, et al. Reliability of clinical measures of glenohumeral motion and internal rotation deficit using a mechanical inclinometer. *J Athl Train*. 2007;42(2):S126-127.

34. Lintner SA, Levy A, Kenter, K, et al. Glenohumeral translation in the asymptomatic athlete's shoulder and its relationship to other clinically measurable anthropometric variables. *Am J Sports Med.* 1996;24(6):716–720.

35. Boon AJ, Smith J. Manual scapular stabilization: It's effect on shoulder rotational range of motion. *Arch Phys MedRehabil.* 2000;81:978–983.

36. Hsu A-T, Hedman JH, Chang JH, et al.Changes in abduction and rotation range of motion in response to simulated dorsal and ventral translational mobilization of the glenohumeral joint. *Physical Ther*. 2002;82:544–556.

37. McClure P, Balaicuis P, Heiland D, et al. A randomized controlled comparison of stretching procedures for posterior shoulder tightness. *J Orthop Sports Phys Ther*. 2007;37(3):108-114.

38. Manske RC, Meschke M, Porter A, et al. A randomized controlled single-blinded comparison of stretching versus stretching and joint mobilization for posterior shoulder tightness measured by internal rotation loss. Sports Health: A Multidisciplinary Approach. 2010;2(2):94-100.

39. Tyler TF, Roy T, Nicholas, et al. Reliability and validity of a new method of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther*. 1999;29:262–274.